Insects in The Ugandan agroforestry systems

An assessment of insect diversity and richness in coffee gardens

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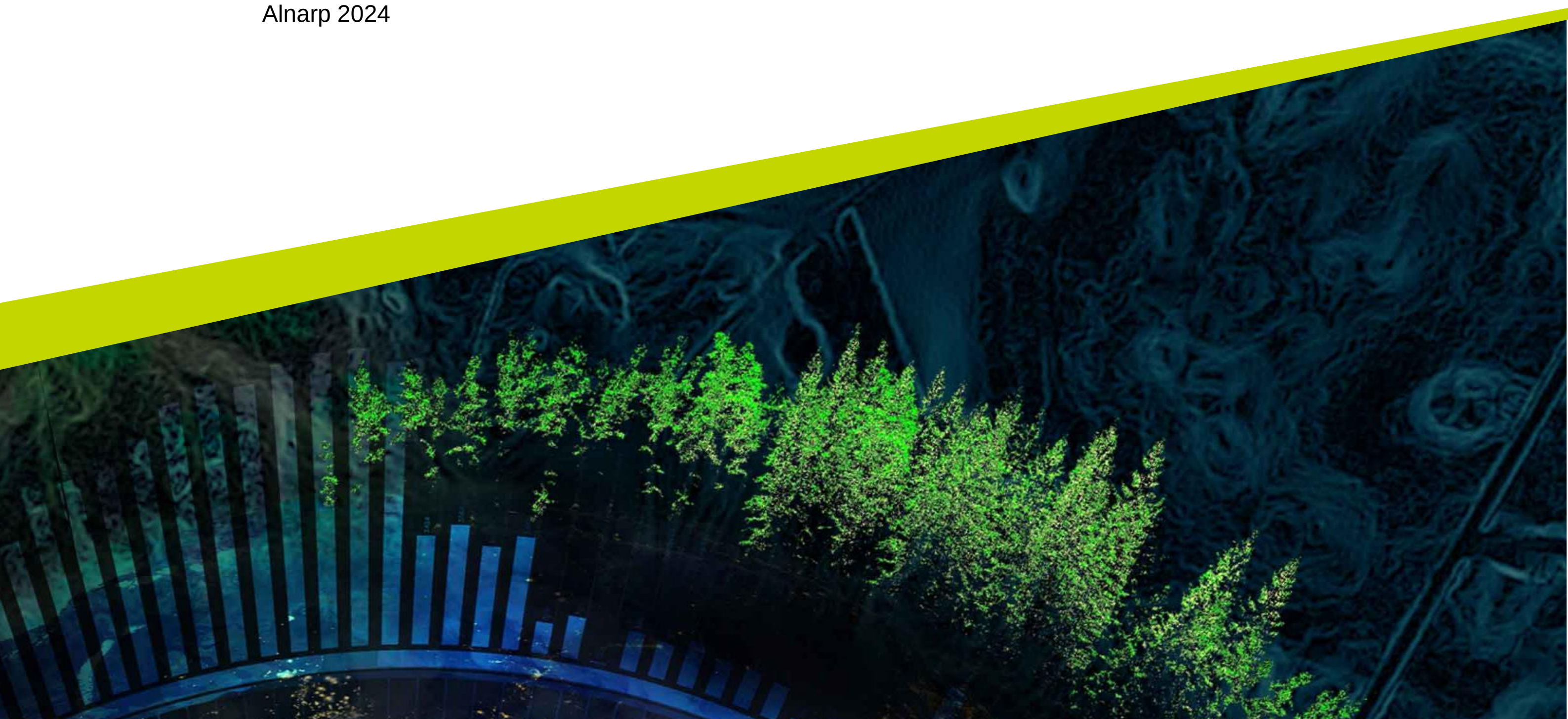

Insects in Ugandan agroforestry systems: An assessment of insect diversity and richness in coffee gardens

Insekter i Ugandas skogsjordbruk: en bedömning av insektsdiversitet och artrikedom på kaffegårdar.

Ellen Anna Josefin Nilsson

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Abstract

Coffee production is a crucial source of income for small-scale farmers in Uganda, and given the significance of primary production, it is important for the country overall. It is the country’s second largest source of income, with strong potential for further growth and development. The coffee is cultivated in agroforestry systems, also called coffee gardens, with various shade trees and crops between coffee trees. Some of these crops and trees are dependent on or benefit from insect pollination, predation, nutrient cycling, ecosystem resilience and other insect-related services. Uganda is a country with a rapidly growing population and land use is becoming increasingly intensified as the population and economy grows. More and more farmers are also using pesticides when they have the financial ability to do so, in efforts to increase crop yield and quality. Not much research has been carried out and very little is known about the insect populations in Uganda, and how they interact with agriculture. Understanding these interactions and agroecosystems may be important for further increase of yields, the growth of the country and protection of nature, as well as to prevent risks associated with fragile ecosystems.

This thesis project aimed to create a baseline assessment for insect species diversity in Ugandan coffee agroforestry systems. Maize farms were also assessed to create a comparison between intensified monoculture maize fields and diverse coffee agroforestry. This baseline may be utilized by farmers or researchers in future projects as benchmark to measure spatial or temporal changes in diversity. An additional purpose of the project was to interview farmers to gather management information, ask about their views on insects and gain an overall understanding of what Ugandan coffee agroforestry looks like. This was done using semi-structured interviews as a tool.

The species diversity baseline was established as averages across farms, and management strategies were compared to diversity scores using correlation tests. Results showed that reported use of pesticide use on the farms did not seem to impact species diversity or richness significantly. Further, crop diversity seemed to have a slightly weaker correlation than anticipated. On the other hand, higher tree richness was closely correlated to both higher insect diversity and richness. Also, a somewhat anticipated but important conclusion was that the coffee agroforestry systems had a significantly higher insect diversity and richness than the maize fields in the study. A total of 4596 insects (including a few arachnids) were collected across 12 coffee farms and 4 maize fields. 323 distinct species were collected and documented.

In conclusion, biodiversity in agroforestry production systems is variable, but much larger than within monocrop systems. The importance of this biodiversity on ecosystem services and resilience, however, requires further study.

Keywords: Agroforestry, Coffee, Diversity, Insects, Richness, Uganda

Foreword

This is my final project in the Agroecology Master's Programme. I was granted the exciting opportunity to carry out the practical parts of my project in Uganda, where I met many farmers who welcomed me with an incredible hospitality and shared their management strategies with me. I learned not only about the practical aspects of utilizing agroforestry systems. I also learned about humanity, Ugandan culture, production systems, economics, the inexorable union between man and nature, and how even small-scale agriculture can create huge impacts.

With a previous bachelor's degree in biology, I joined the Agroecology master in Alnarp. Agriculture simply seemed like another set of systems within the biological framework I was already so interested in, with additional opportunities to make a practical impact. In my experience, agriculture had mostly been described as a cause of problems, and thus a field which needs improvement. For parts of my education, I took independent courses at multiple universities. Some courses focused on ecosystems, climate, and what we can do to protect the world. Other courses focused on productivity, resource management and how biology can be utilized to improve living standards without necessarily addressing the environment. I have also been active as an environmental and biological activist.

I passed through some social circles where the only acceptable produce was organic, and consuming genetically modified crops was frowned upon. And I passed through other circles, where the only goal was intensification. Debates around environmental conflicts are often incorrectly presented like a coin, nature on one side versus humanity on the other, and bridging that gap can feel tricky at times. I believe that one of the most important obstacles for humanity today is to bridge that gap and find a mutually beneficial middle-ground. I am convinced that agroecological values will help us with that.

Researching Ugandan coffee gardens allowed me to see a version of agriculture which is more connected to the nature around it. Therein lies a middle-ground where people utilize natural resources without excessive exploitation, and the farming systems do not only exist alongside ambient biodiversity but also enrich it.

Thank you for taking the time to read my thesis.

Yours sincerely,
Ellen.

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Abbreviations

EU	European Union
SSI	Semi-Structured Interview
SDI	Shannon Diversity Index
UCDA	Ugandan Coffee Development Authority

1. Introduction

As the 2nd largest export product of the country, coffee plays a crucial role in the socioeconomic development of Uganda. In 2015, the coffee sub-sector employed over 5 million people. It remains a primary source of income for particularly the rural poor as most coffee farms are small-scale (Verter et al. 2015). Most of the Ugandan coffee is exported since the domestic consumption is minimal, and most of this exported coffee ends up in the EU (Verter et al. 2015, UCDA 2024). Reversely, Uganda is also important for the coffee market, since the country is within the top 10 of global exporters, and the second biggest exporter of coffee in Africa after Ethiopia (Verter et al. 2015). However, despite coffee being an important cash crop, the production has been facing problems such as poor genetic quality of crops, poor soil quality, harsh weather, pests, diseases and overall low productivity (Diiro et al. 2023, Oduol & Aluma 1990). Multiple factors underlie the low productivity, but there are opportunities for growth. One massive issue for the farmers is that the green, unprocessed beans are sold at a relatively low price. These coffee beans become dried and roasted elsewhere, which adds significant value to the crop. Farmers only receive a small fraction of the money generated from fully processed beans, and carrying out processing themselves can be difficult or impossible due to lack of resources. It might help farmers to set up economic collaborations where they process and sell produce together, but this is unheard of so far in the region visited during the study. This is a country which is likely more economically dependent on its agriculture than many rich countries are, and where improvements in sustainable productivity can make huge long-term differences.

Coffee is usually grown with shade trees to protect the crop from strong sunlight (Justine et al. 2019). This encourages intercropping which is primarily done with banana, since it is taller than coffee and a staple crop in the country. But many other shade trees can be used to increase productivity and diversity, including medicinal trees or fruit trees like mango, cacao, avocado, apple, orange, jackfruit and papaya (Oduol & Aluma 1990). Between the trees, other important food crops such as cassava, pineapple, maize, beans, sorghum, peanuts, yam and potatoes can be planted (Justine et al. 2019). These agroforestry systems often also contain livestock, especially poultry, which can be allowed to roam freely on the farms (Oduol & Aluma 1990). When containing diverse combinations of crops, trees and livestock, these places are sometimes called coffee gardens.

Coffee gardens may yield slightly lower coffee outputs than more intensified and less diverse systems, but there are many other benefits to them. Diverse agroforestry can support food security, increase nutrient diversity, enrich biodiversity and sequester carbon (Justine et al. 2019). Increasing plant species richness in agroecosystems may lead to benefits especially concerning pest and disease management, for example through strategic selection of companion plants and cover crops. Depending on the context of the agroecosystems and which plants are used, the positive management effect on pests has been proven in multiple field-trials and continues being researched and applied around the world (Ratnadass et al. 2021). One trade-off for highly diverse agroecosystems and their potentially lower yields is that they may allow for premium prices due to certifications like Fairtrade or Organic (Ratnadass et al. 2021). It is, however, important for the sake of financial sustainability to keep in mind whether there are accessible markets which exist for this certified produce (Ratnadass et al. 2021). Also, small scale farmers in Uganda cannot afford labels, which makes labels benefit large-scale farms more. Their practices are sometimes by default organic, but this does not matter in the marketing of their produce.

Agroforestry systems are sometimes portrayed to encourage insect diversity and services, such as pollination, pest predation and nutrient cycling, as they generally have higher diversity than monoculture agriculture (De Beenhouwer et al. 2013; Santos et al. 2022). Pollination from insects, especially wild non-bee populations, is crucial for food production and security (Requier et al. 2023). Overall, insects are crucial for ecosystems around the world, being essential in the base of trophic interactions of most communities (Wagner 2020). Wild populations of pollinator species may be less sensitive to anthropogenic activity and can provide stable crop production in areas where bee populations have declined (Requier et al. 2023). Coffee is not strictly dependent on pollination, as the plants are autogamous, but it reliably increases yield (by 31% on average) (Hipólito *et al*. 2018). Biodiversity can thus improve yields overall on farms, and more intensely managed systems with lower diversity have in some cases been proven to have lower yields (Hipólito *et al.* 2018).

Unfortunately, insect populations are dwindling all over the world, not only in the case of bees which are more well-known pollinators, but also for many other groups of pollinators (Garibaldi et al. 2013, Wagner 2020, Requier et al. 2023). Garibaldi *et al*. (2013) researched the efficiency of wild pollinators compared to domestic honeybees, and results showed the former being significantly more important for fruit sets and overall productivity across flowering plants. Thus, pollination by honeybees may only supplement wild pollinators, rather than having the potential of replacing them (Garibaldi et al. 2013). Monitoring insect populations is important as a first step to investigate the threats they face, largest of which globally being climate change, invasive species and above all, agricultural intensification (including habitat destruction and pesticide use)

(Wagner 2020). To reduce the loss of insects and the threat towards pollinators, as well as rebuilding resilience in agroecosystems, management of these systems needs to transition towards ecological sustainability (Requier et al. 2023, Wagner 2020). Most of the current scientific knowledge on the decline of insect populations is in western and northern Europe, especially focusing on bee populations (Requier et al. 2023, Wagner 2020). Meanwhile, there is much less knowledge on the situation in Africa and Asia, and on other insect groups (Requier et al. 2023). Investigating insect populations in rural Ugandan farmlands may therefore grant an opportunity to quantify diversity in a scarcely studied area, before significant intensification of agriculture happens. Further, farmers are a potential main driver for sustainability. This means that understanding the significance of biodiversity in farmlands may be the best way for us to maintain and protect it.

2. Study objectives and questions

My hypothesis is that insect abundance and crop diversity as well as management strategies are positively correlated and can be used to enrich ecosystems and to more accurately utilize integrated pest management in rural Uganda. The main research question is as follows: Do agroforestry management strategies and crop richness impact insect diversity and richness on the farms? This question is addressed by measuring biodiversity in coffee production systems in agroforestry settings and comparing results with maize monoculture settings. Statistical analysis of management strategies is conducted using reported answers from semi-structured interviews with farmers, and insect data is collected from hanging bottle traps on farms. Once insects are collected and identified down to orders, pictures are taken through a digital microscope, assigned species ID's and documented.

3. Materials and Methods

3.1 Research location

The project was carried out in Kamuli District, Uganda (Figure 1). Most farms were in the Namasagali area or neighbouring towns, relatively close to each other, and should thus have similar ecological and climatic conditions. Namasagali is in the northwestern Kamuli District, right next to the Nile River. Most of this area was quite flat, with the slightly lower wetlands between towns being utilized for rice farming and cattle grazing. Higher, drier land mostly consisted of maize fields, agroforestry farms and various buildings. The coffee farms and maize fields analysed in this project were located on the slightly higher land. Despite this, there were reportedly regular issues with floods during the wet season, and issues with droughts during the dry season.

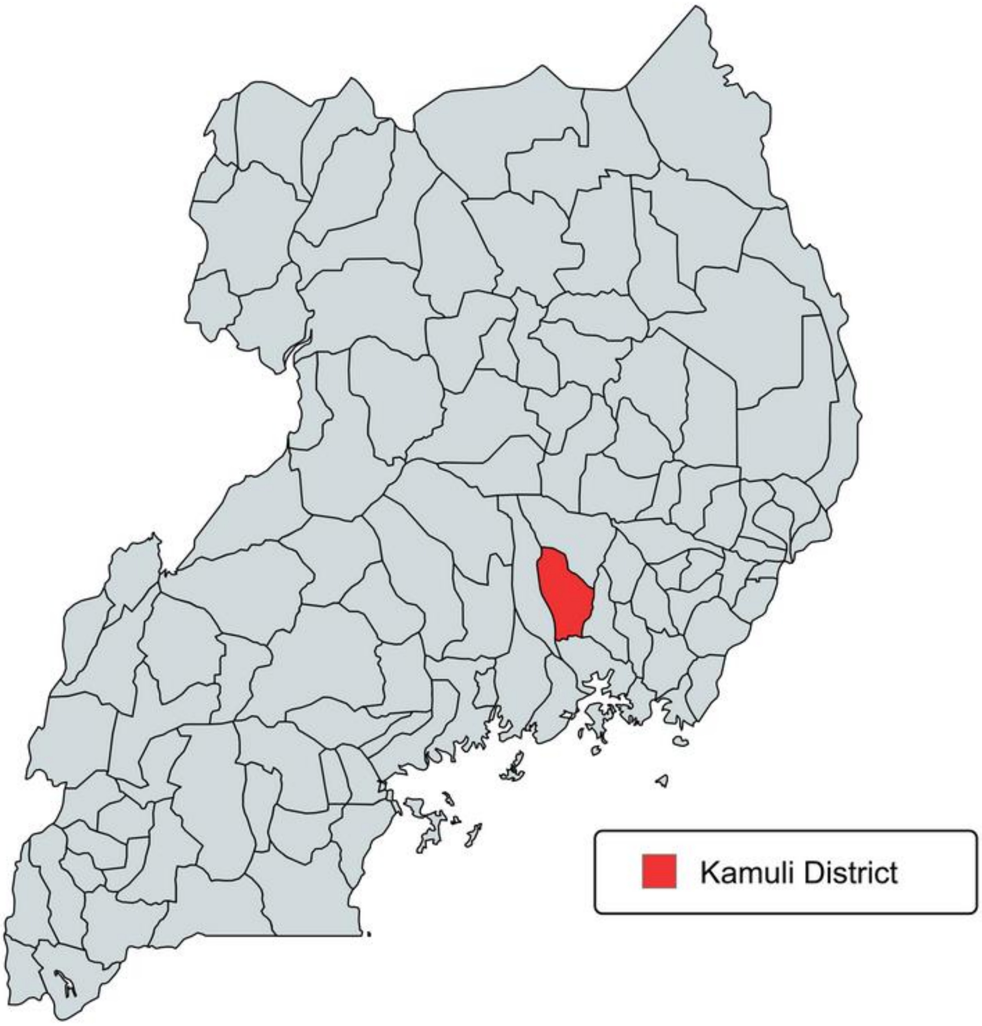

Figure 1. A map of Uganda, with borders between each district. This project was conducted in Kamuli District, highlighted in red above. The district is in the south-eastern part of Uganda. The farms researched were mostly located around Namasagali, a town in northwestern Kamuli district. (Created using mapchart.net).

3.2 Trapping method

Insect traps were crafted from used and clean 500ml plastic water bottles. They were similar in shapes, and all of them were entirely transparent with no labels on. Two U-shaped openings were cut on opposite sides of each bottle and were pulled up to create protective structures against rainfall into the bottle. A sturdy metal wire was pulled through and secured into the bottlecap for hanging the trap in trees or poles. The lure inside the trap consisted of a banana liquor called Waragi, mixed with equal parts water and around 5ml of liquid soap. Waragi contains around 40% ethanol, but since this was locally crafted liquor, the exact percentage was not known. Ugandan Waragi is a type of gin which can be made of various crops, such as millet, cassava, banana or sugarcane (Gatsiounis 2010). In this case a banana version called Kasese was used, originating from the Kasese region. Waragi has been used in previous master's projects as an insect attractant, and was deemed successful. While the potential of different insect lures has not been thoroughly studied, it is likely that it is not primarily the ethanol that attracts insects, but rather the smell of fermented fruit and other compounds within the liquor. It was estimated that any given trap type and method would only give a representative view of insect populations, since the method will create bias. But bottle traps were chosen due to efficiency and the ease of replication.

Six traps per farm (or maize field) were placed with at least 50m between each trap, during walks with farmers. There was no maximum distance between traps, and the distance varied depending on the farm size. However, most farms were of similar sizes, and the traps were usually within eyesight (or approximately 80-100m) of each other. After 2 weeks, the trapped insects were collected into labelled jars with a brief documented description of the surrounding area near each trap. During collection, most of the liquid in the traps was filtered out and replaced with Waragi to prevent insect deterioration.

3.3 Identification method and data collection

Trapped insects were individually analysed in a digital microscope (Tomlov model DM601) and identified down to insect order and were easily accessible further down to family level. As keys were not available, insects were further grouped into 'species' groups, by grouping individuals which appeared the same species. Each of these insect species was assigned a species ID to assess the abundance of each present species and document patterns across farms. Images of each insect species were taken through the digital microscope and stored in a compiling document. Due to damage some insects were difficult to identify down to their order and were placed in an "un-identified" category in which they were still given individual species IDs since their visible features were still enough to differentiate from other encountered species. They were simply given ID's which were not placed in orders, but in their own "unspecified" category. The ID's and abundance of each species was documented in a spreadsheet, displaying which farm and trap the insects came from. Other arthropods such as a few arachnids were also documented, as they were found in some of the traps. But they represented a relatively small part of the trapped arthropods overall. 14 species were arachnids, making up approximately 4% of the total 323 trapped invertebrate species. 40 arachnid individuals were trapped, making up approximately 0.9% of the total 4596 trapped invertebrates. Arachnids were the only non-insectoid animals found in the traps.

3.4 Data analysis and statistics

Data from total captures of traps was not normally distributed, as discovered using Shapiro-Wilks normality tests, so the methods of analysis had to be nonparametric.

$$H = -K \sum_{i=1}^{n} P_i \, Log(P_i)$$

Above is Shannon's formula for diversity, also known as the Shannon-Wiener Diversity Index (SDI) (Shannon 1948, p.11). It was originally created to describe entropy and uncertainty in communication but was later adopted within ecology to assess richness in populations. The formula considers both richness and evenness of every species in any given community, granting an overview of biodiversity. When used as an ecological formula, the K is removed, and Log is changed to Ln. This results in the following formula:

$$H = -\sum_{i=1}^{n} P_i \, Ln(P_i)$$

Formula components denote the following:
H = Shannon Index value.
P_i = Proportion of individuals in species i.
n = Number of species in the community.

Insect species diversity was calculated using the SDI and given a Shannon index value for each trap, as well as a richness value (number of species). The Shannon index value and richness value was used in statistical analysis in connection with reported management strategies from each farm's interview. The strategies analysed were farm-type (coffee garden vs maize field), whether insecticides or herbicides were used in the last year, crop species richness and tree species richness.

3.5 Timeline

Field work with trapping and interviews started on 6th of May with the first coffee farms. The last coffee farm traps were collected on the 4th of June. The first corn field traps were placed on the 27th of May, and the last corn field traps were collected on the 11th of June. There was a +/-1 day time-limit to collect the traps within 2 weeks, so some traps were collected a day early or late. However, this was not expected to result in issues or inaccuracies and most traps were collected precisely after 2 weeks had passed. The risk of temporal trends was considered, but difficult to avoid in the method. This was to be taken into consideration. However, as mentioned in the discussion, it was most likely not a problem for the data as weather patterns did not change much throughout the project.

3.6 Interview structure

A semi-structured interview (SSI) was conducted with the participating farmers to assess the agroecological values on their farm, to understand how the farm is managed, and to understand the farmer's views on insects. The format of a SSI was chosen because of the opportunity to ask broad follow-up questions and gain a deeper understanding of Ugandan agriculture and the farm management overall, as well as to create a more comfortable atmosphere with farmers. These main reasons suit the strengths of a SSI, according to a report by Adams (2015). The sample size of farmers to interview was also an acceptable size to conduct SSIs with, while a larger sample size could have required more time-effective methodology. The farmers were expected to be more comfortable and used to open one-on-one discussions about their management, rather than filling out forms or sitting in large groups. Some of the questions did not lead to any statistical analysis connected to insect diversity or richness. This was because of an interest in gaining comprehension of the broader agroecological scope of Ugandan coffee cultivation.

Interviews were conducted on-farm, and the questions were translated by a local translator known to most of the farmers beforehand. Notes on the answers were taken by hand on paper during the interview, and later copied onto a digital document. The entire interview took approximately 40-60 minutes per farm, depending on how much the participants felt like elaborating on their answers. Each farmer was given a "Farm ID", which was assigned to interview responses as well as the collected insect data from their farms. In this way, responses and insect data became anonymized once they were documented and statistically processed in a spreadsheet.

3.6.1 Semi-Structured Interview Questions

The most central questions asked to farmers were regarding whether they have used insecticides or herbicides recently (within the past year), how many crop- and tree types they have and what their opinions are on insects. The first 2 were the questions used in statistic analysis, as they were deemed most important and likely to make a difference to insect populations. Other questions were also asked during the semi-structured interview in order to gain a broader view of coffee agroforestry, even though they were not used in statistical analysis. The use of pesticides in Ugandan farming seems to have increased in recent years, due to more farmers having access and money for it. However, it did not seem to have been used much in previous decades.

4. Results

4.1 Average Diversity and Richness Data

During the project, a total of 4596 arthropod individuals were captured, granted an ID and analysed. These made up 323 different species, 14 of which being spiders and the rest being insects. Spiders are included as they interact with the insect populations and are also important for ecological reasons. The following tables (1 & 2) contain the average SDI score and species richness from each studied farm. Table 1 contains data from the coffee farms, and table 2 contains data from the maize farms. As seen in the bottom of the tables, both the SDI score and species richness is on average higher in the coffee farms than in the maize farms.

Table 1. The average SDI score and species richness from insect traps on each coffee farm, and the overall coffee-system average.

Farm ID	Shannon Diversity Index Score	Species Richness
1	1.631333333	14.66666667
2	2.0144	15.2
3	2.276666667	13.16666667
4	2.283333333	13.5
5	2.4	14.33333333
6	2.33	16.5
7	1.653333333	12.33333333
8	2.0205	21.83333333
9	2.068333333	10.83333333
10	1.8565	11.16666667
11	2.48	17.5
12	2.285	16.33333333

Average	2.108283333	14.78055556

Table 2. The average SDI score and species richness from insect traps on each maize farm, and the overall maize-system average.

Farm ID	Shannon Diversity Index Score	Species Richness
13	2.11	11.5
14	1.615	10
15	0.999	9.166666667
16	1.968333333	14.33333333
Average	1.673083333	11.25

4.2 Statistical results

Shapiro-Wilk normality tests proved that only data from the Maize-traps was normally distributed (W = 0.9, p = 0.6), while the coffee data (W = 0.9, p = 0.001) and combined data was not normally distributed. Because of this reason, further analyses were conducted through nonparametric methods. There was no significant difference in variance between coffee and maize farm diversity, according to a Levene’s test for variance.

Wilcoxon Rank Sum tests were carried out to analyse differences between farm types regarding insect diversity (Figure 1) and richness (Figure 2). There was a similarly large difference in both. Diversity difference was W = 1233.5, with p = 0.0011, and richness difference was W = 1231, p = 0.001135. Thus, the diversity and richness seem to go hand in hand.

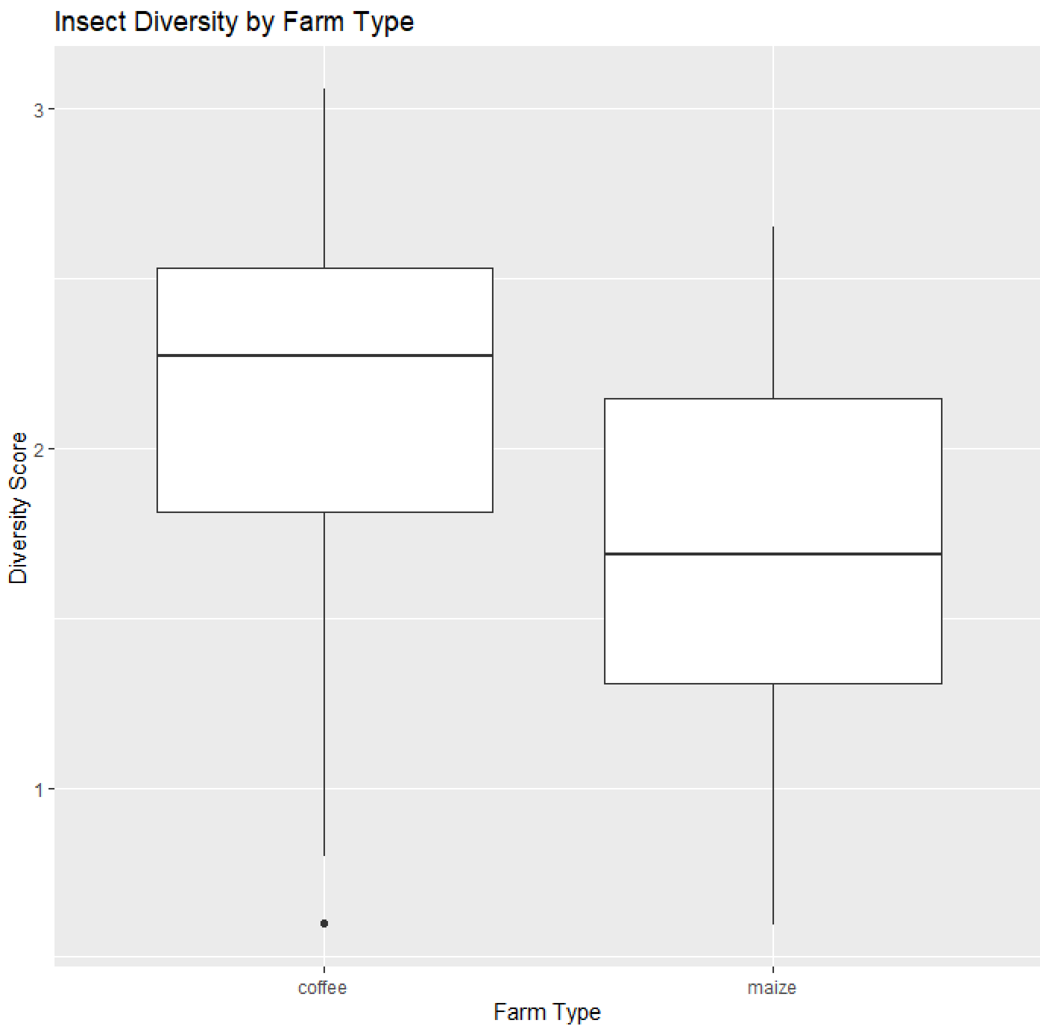

Figure 2. The difference in insect diversity by farm type. Diversity Score on the y-axis and Farm Type on the x-axis display the difference, with coffee farms having higher insect diversity than corn fields. A Wilcoxon Rank Sum test resulted in values W = 1233.5, p = 0.001, showing a significant difference.

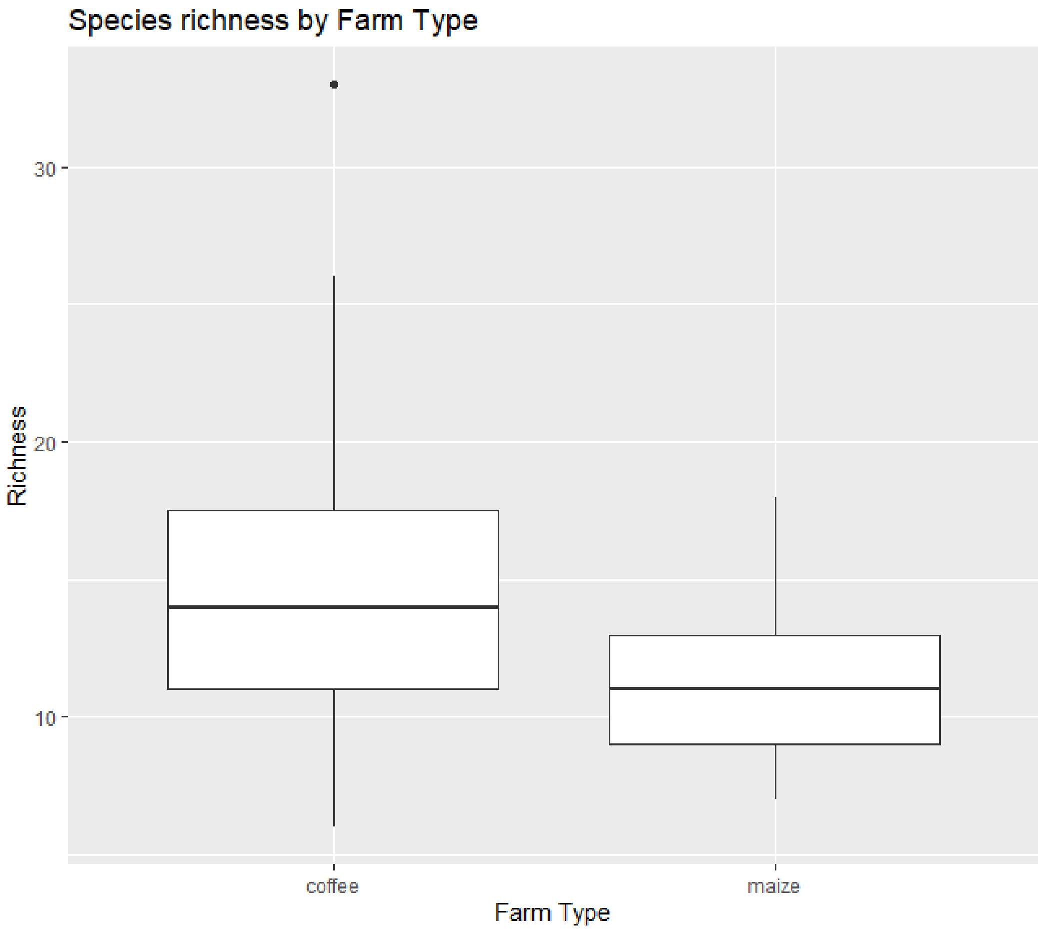

Figure 3. The difference in insect species richness by farm type. Richness on the y-axis and Farm Type on the x-axis display the difference, with coffee farms having higher richness than corn fields. A Wilcoxon Rank Sum test resulted in values W = 1231, p = 0.001135, showing a significant difference.

Another 4 Wilcoxon Rank Sum tests were carried out to analyse potential differences in diversity or richness depending on insecticide- and herbicide use. There was a significantly lower amount of insect richness in correlation with use of herbicides (Figure 6) (W = 1270.5, p = 0.0111). The other 3 tests, looking at insect diversity and richness correlating with insecticide use, and diversity with herbicide use, did not yield significant differences (Figures 3, 4 & 5).

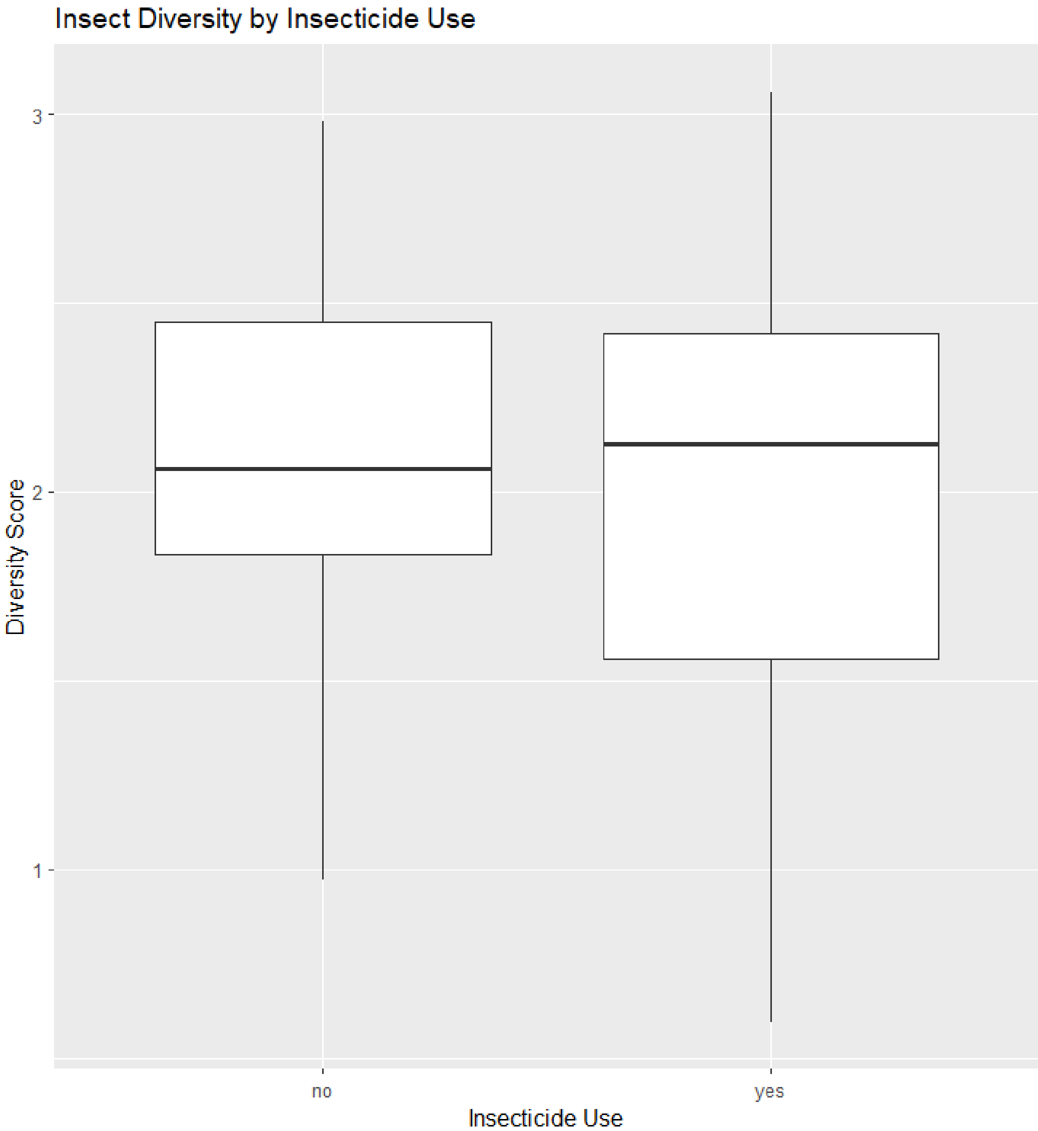

Figure 4. There did not appear to be a significant difference in insect diversity due to insecticide use on coffee or corn farms, as seen in this graph. A Wilcoxon Rank Sum test resulted in a non-significant difference (W = 1174, p = 0.3406).

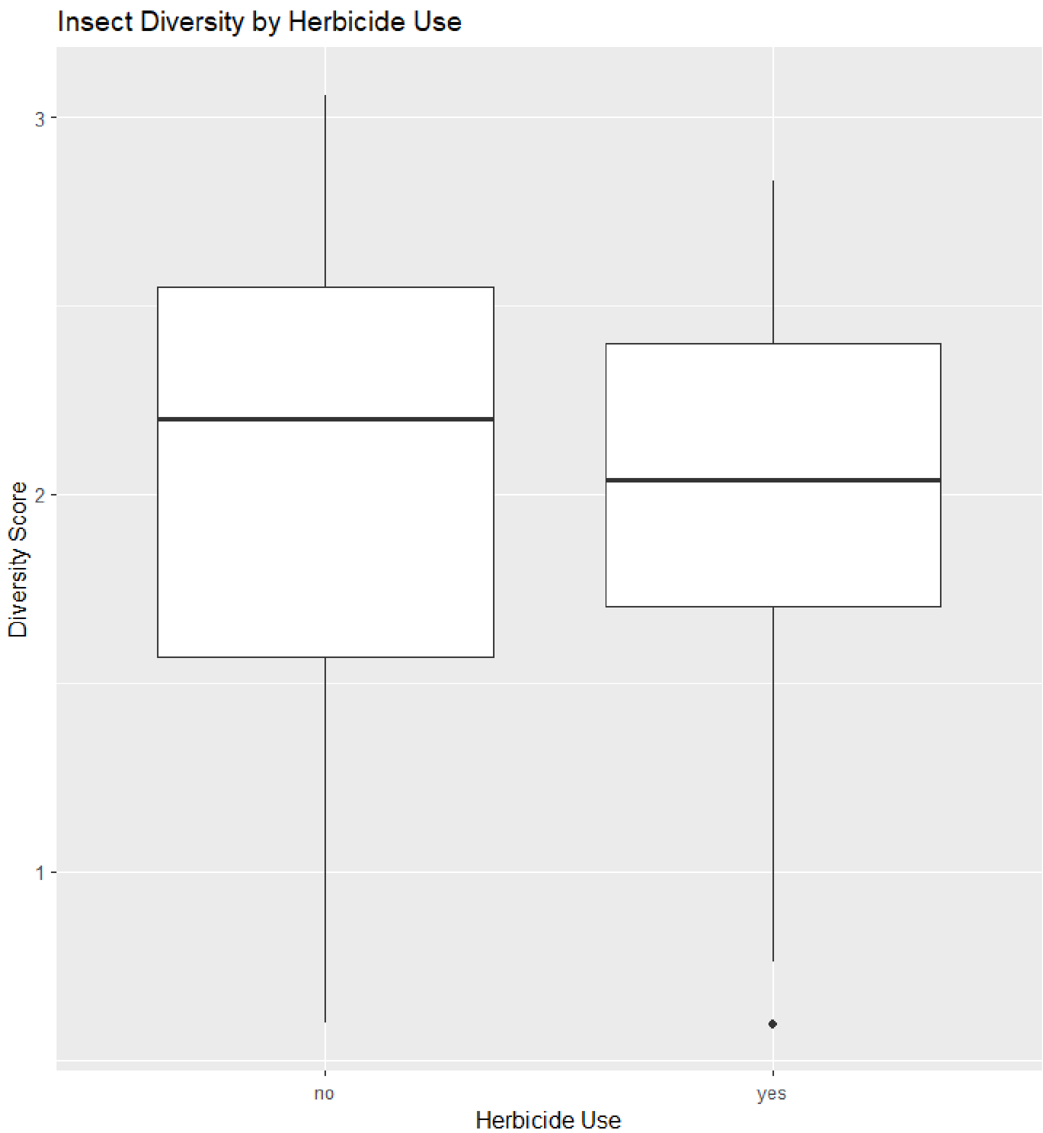

Figure 5. There did not appear to be a significant difference in insect diversity due to herbicide use on coffee or corn farms. A Wilcoxon Rank Sum test resulted in a non-significant difference ($W = 1021$, $p = 0.6078$).

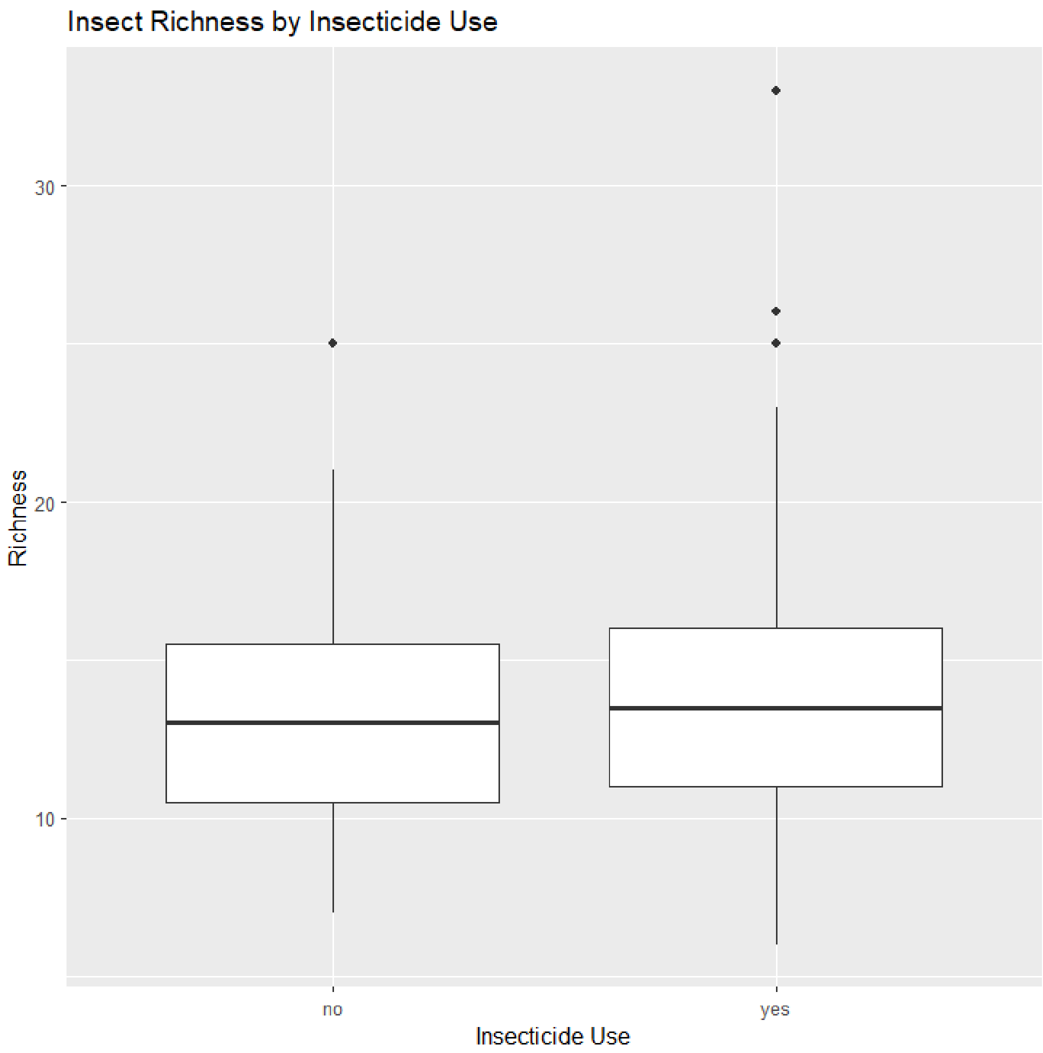

Figure 6. There does not appear to be a significant difference in insect richness due to insecticide use on coffee or corn farms. A Wilcoxon Rank Sum test resulted in a non-significant difference ($W = 956.5$, $p = 0.4713$).

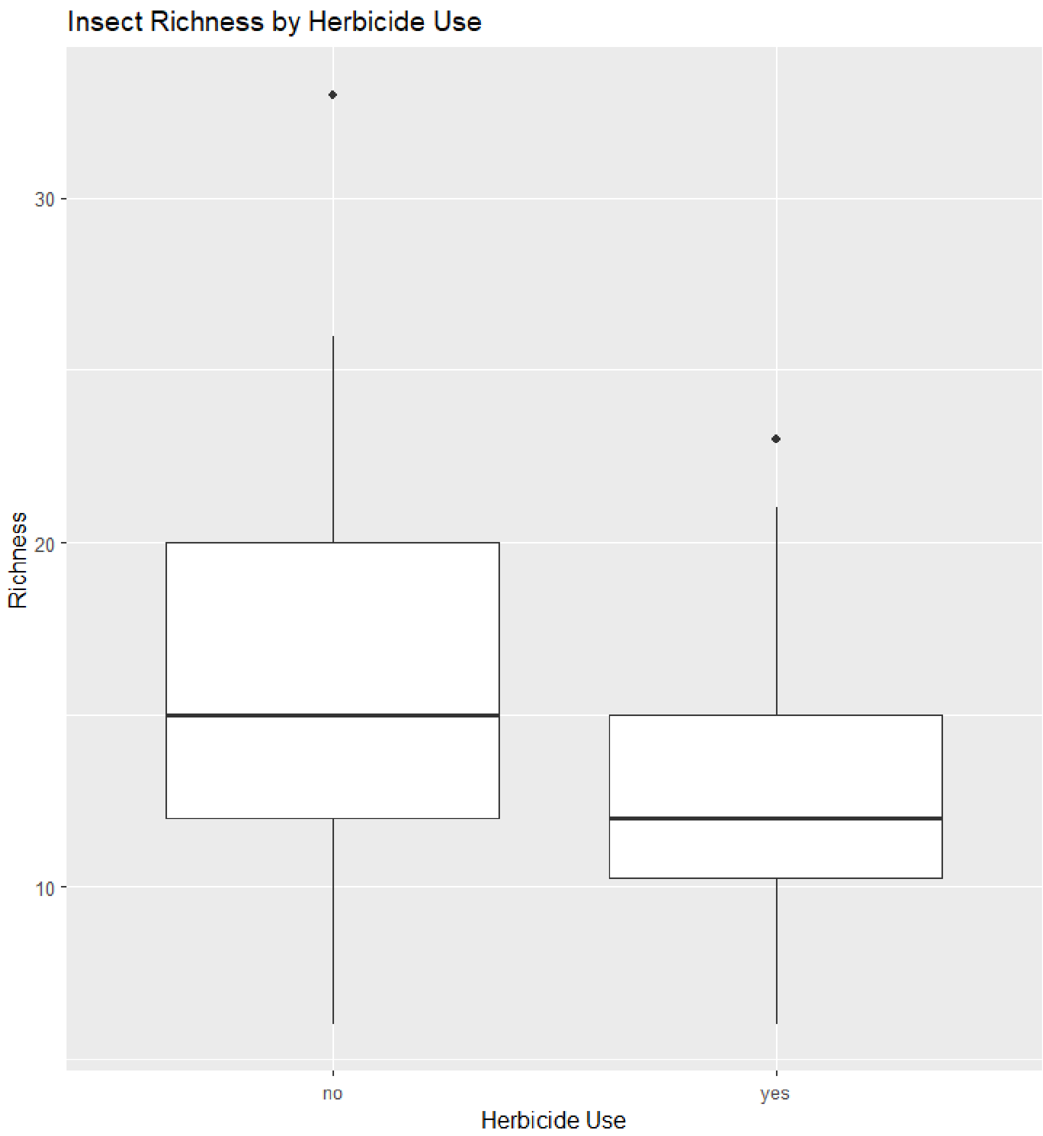

Figure 7. Unlike in the previous 3 graphs (Figures 3, 4 & 5), there seems to be a significant effect on insect richness from herbicide use. A Wilcoxon Rank Sum test resulted in values W = 1270, p = 0.0111.

Spearman's Rank Correlation tests were conducted to analyse whether there was a correlation between diversity and species richness and crop- or tree richness. These correlation tests all include data from both coffee farms and maize fields. "Crops" in these tests only included non-tree crops, while the "trees" in the tests included all trees kept for all purposes, for example both shade trees and fruit trees. One might argue that fruit trees also count as crops, but for the sake of removing overlap, they only count as trees. Their richness is the amount of tree species, but the amount or diversity of trees was not included in the study for the sake of limiting the scope. There was no significant correlation between increased insect diversity and increased crop richness, although there was a very slight trend (Figure 7). However, there was a slight, significant correlation between insect species richness and crop richness (Figure 8). Both insect diversity and species richness had significant correlation with tree species richness on the farms (Figures 9 & 10).

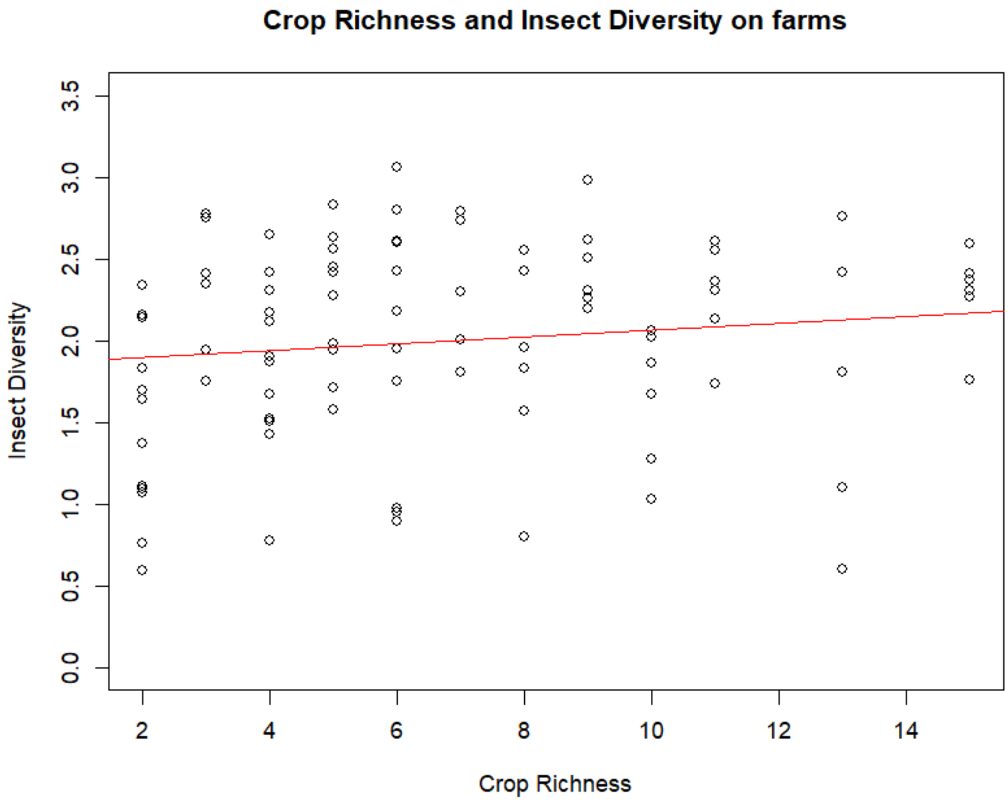

Figure 8. While there is a very slight trend towards increased insect diversity with increased crop richness, a Spearman's Rank Correlation test proved there was no significant difference (p = 0.09).

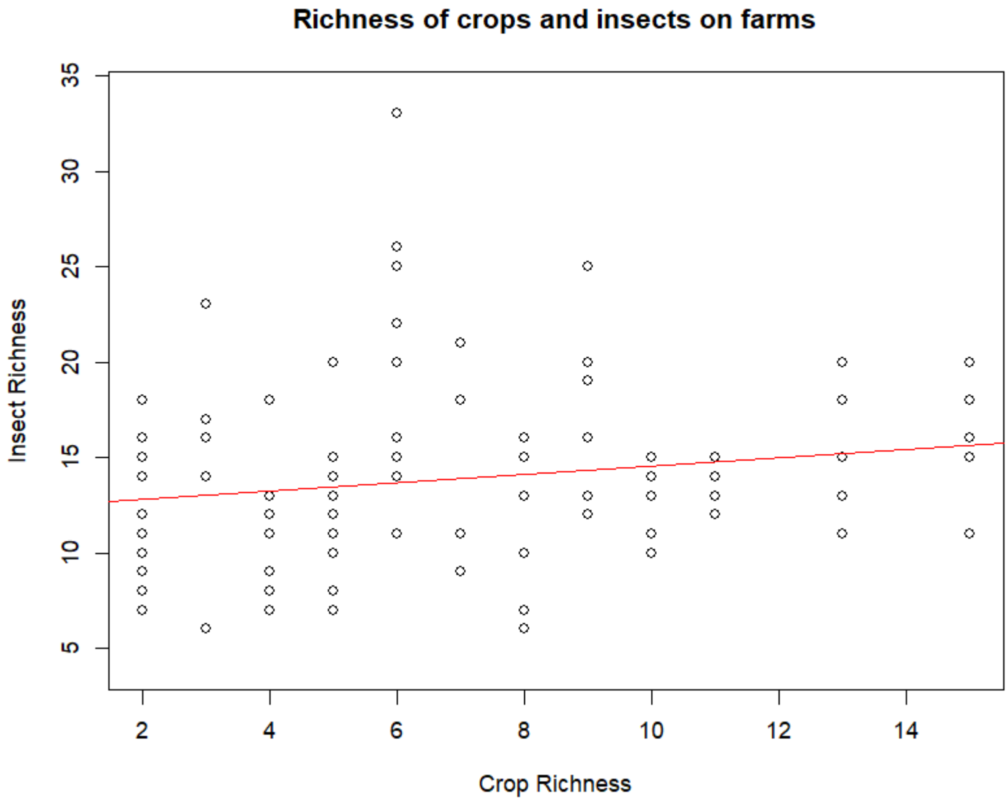

Figure 9. There was a slight but statistically significant correlation between crop richness and insect richness, as seen in the graph. A Spearman's Rank Correlation test resulted in values of rho = 0.23, p = 0.02.

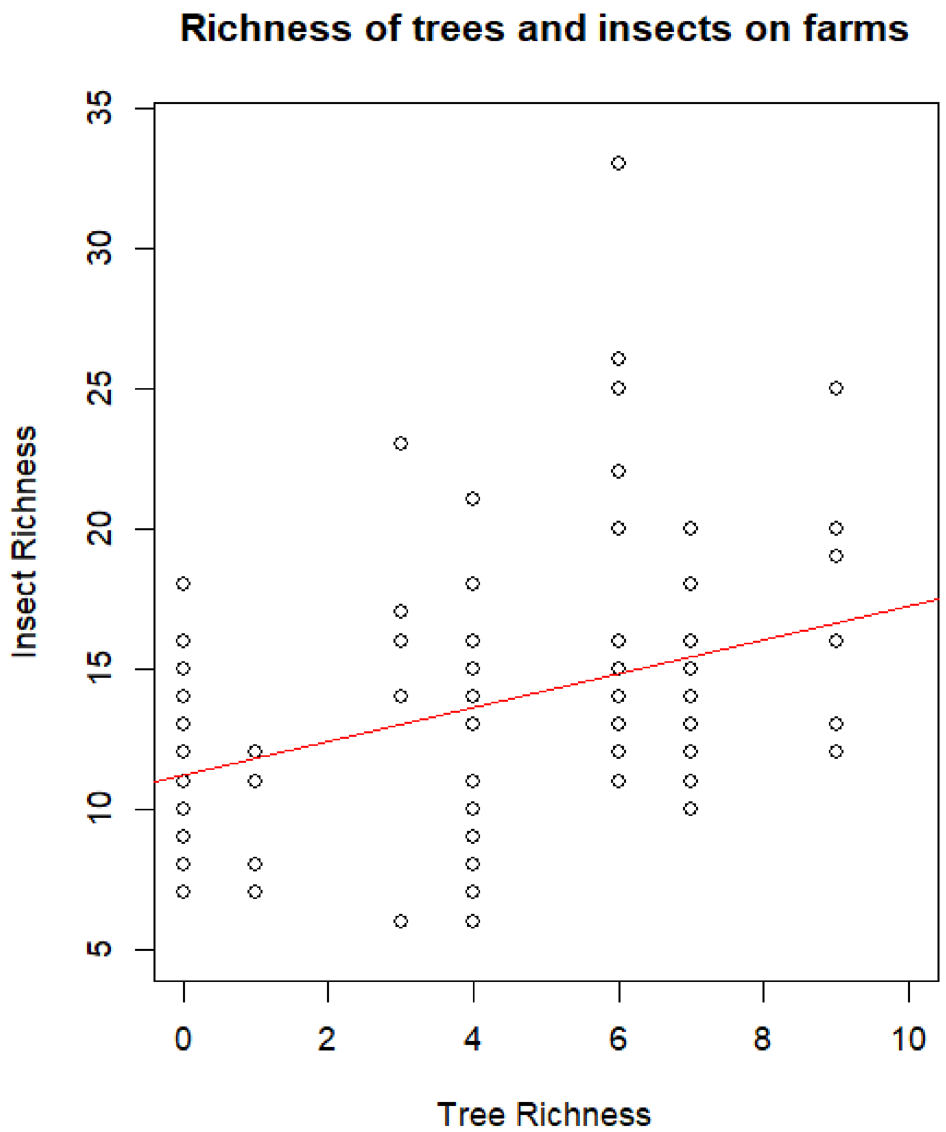

Figure 10. There was a correlation between tree richness (including crop trees) and insect richness. A Spearman's Rank Correlation test resulted in values of rho = 0.35, p = 0.0005. This correlation was stronger than the correlation between crop richness and insect richness + diversity.

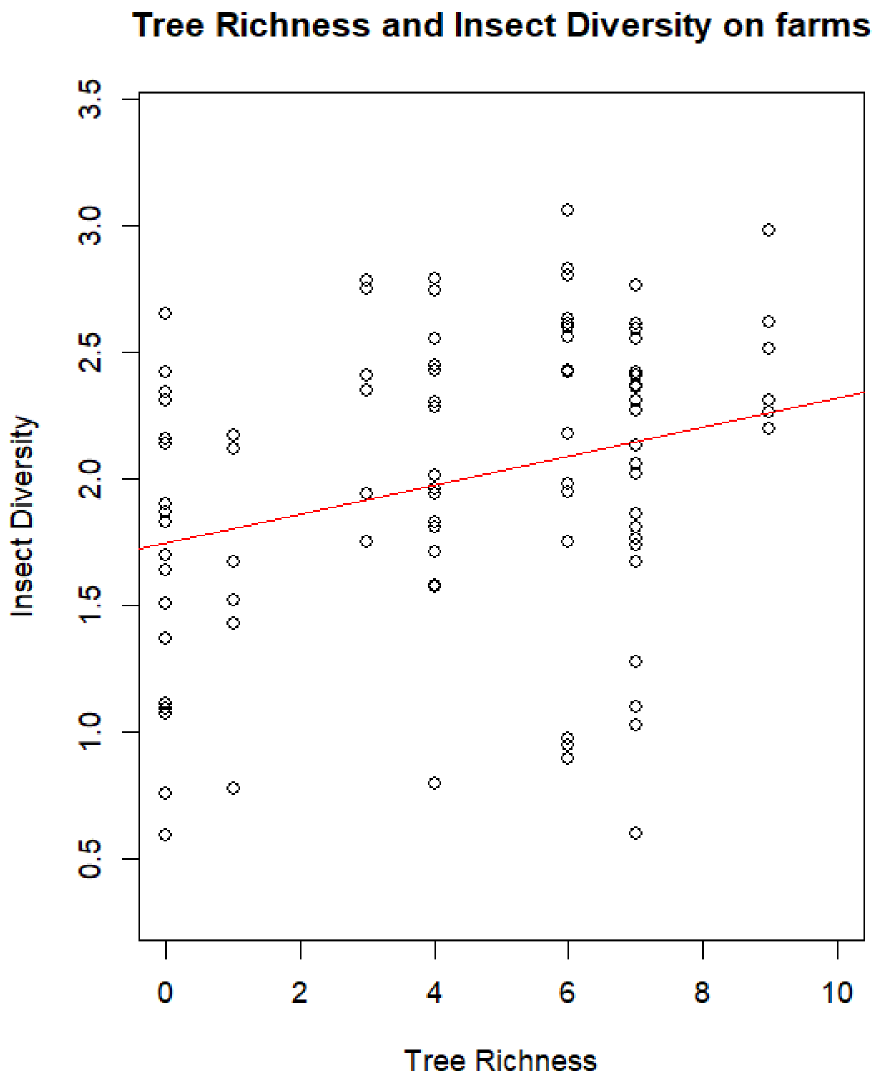

Figure 11. There was a correlation between tree richness (including crop trees) and insect diversity, like figure 9 above but slightly weaker. A Spearman's Rank Correlation test resulted in values of rho = 0.25, p = 0.015.

4.3 Interview results

The semi-structured interview consisted of questions and topics which were not used in statistical analysis connected to insect populations. This was because one secondary goal of the project was to create a general understanding of Ugandan agroforestry, but not all factors are likely to affect insect populations. Some of these factors may be whether farmers share knowledge with others, or how much of their produce is sold vs consumed in the household. All data from the interview was self-reported. Table 3 shows average number of years of experience, acres of farmland, number of crop types and tree types. This gives a rough overview of the average data comparing coffee vs. maize systems. Table 4 shows an overall percentage of insecticide use, herbicide use, how many of the farms have a nearby water source and how many have beehives.

Table 3. The average amount of experience, farmland, crop types and tree types for coffee- and maize farmers involved in the study.

	Years of experience	Acres of farmland	No. of crop types	No. of tree types (including crops)
Average Coffee	25.7	5.2	8.2	5.8
Average Maize	15.5	3.9	3	0.2

Table 4. The proportions of coffee- and maize farmers in the study which utilize insecticides, herbicides and have nearby natural water sources or beehives. n = 12 coffee farms and 4 maize fields.

	Insecticide use	Herbicide use	Nearby water source	Beehives
Coffee	58%	58%	25%	16%
Maize	75%	100%	50%	50%

Upon being asked about their opinions on insects, all farmers responded in an overall negative or neutral way. 10 responded with a mostly, or entirely, negative perception. And 6 farmers responded with a mostly neutral perception, while no farmers reported a mostly positive view on insects and their services. The most common response was that bees and other pollinators are somewhat beneficial, but that all other insects are either unimportant, bothersome or terrible for the farm. Some responded that they saw no benefits of having any insects, and some were unaware that insects could help pollinate crops. There was no other positive insect service mentioned aside from pollination, and this service was only mentioned to be carried out by bees and possibly butterflies. The most common reply was that bees are the only good insects, and the rest are bad. This was said by 9 of the interviewed farmers. 3 farmers stated that pollinators overall are beneficial, not mentioning specific ones. 1 farmer stated that bees and butterflies are beneficial, and 1 farmer stated that bees and earthworms are beneficial. 1 farmer said that all insects are terrible or non-beneficial, and that he wanted to be rid of all insects on the farm. And it was stated by 2 farmers that ants and flies are very annoying and possibly harmful insects. Ants were one of the main insect groups that farmers used insecticides against, as they were considered disruptive or harmful during the harvest seasons, since they become aggressive and bite farmers who come near their colonies.

The additional semi-structured interview questions were not used for statistical analysis of insect populations on the farms, as they were deemed more general and not likely to strongly affect the populations on this sample size. However, they may still shine a light on the management strategies of farmers in the study, and the current state of Ugandan agroforestry systems. Note that farm ID 1-12 were the coffee agroforestry farms, and farm ID 13-16 were maize fields. This is highlighted using red colour for coffee farms and yellow colour for maize fields.

Do you have animals on your farm? Which ones?

Table 5. The types of animals to exist on each coffee farm or maize field, as reported by each farm's respective owner.

Farm ID	Animals
1	Chickens
2	-
3	Chickens
4	Chickens, Rabbits
5	Chickens
6	-
7	Chickens, Ducks
8	Chickens
9	Chickens
10	-
11	-
12	Chickens, Cows, Pigeons
13	-
14	-
15	-
16	-

Table 5 shows the types of animals found on the farms, usually roaming freely. There was no counting of the animals, and in some cases the chickens on-farm belonged to neighbours. In some cases of no animals being reported, there is still a very likely chance of neighbouring farm animals roaming onto the studied farms. The maize fields did not have animals in them, aside from some potential chickens which roamed the areas.

Do you use manure on your farm?

Table 6. The self-reported use of manure on farms, approximately in the past year.

Farm ID	Yes (Y) / No (N)
1	Y
2	Y
3	Y
4	Y
5	Y
6	Y
7	Y
8	Y
9	Y
10	N
11	Y
12	Y
13	N
14	Y
15	N
16	N

Table 6 shows that most of the farms used manure as a fertilizer, at least somewhat recently. Most of the farmers stated that manure improves the soil. Multiple farmers also stated that they would like to add more manure, but that they either cannot afford more or that their livestock is not producing enough. It is possible that this periodic deficiency in added nutrition and soil improvement input is a limiting factor for crop yield quality and quantity.

Do you use artificial fertilizer on your farm?

Table 7. The self-reported use of artificial fertilizer on farms, approximately in the past year.

Farm ID	Yes (Y) / No (N)
1	Y
2	N

3	N
4	Y
5	N
6	N
7	N
8	N
9	Y (rarely)
10	N
11	N
12	N
13	N
14	Y
15	Y
16	Y

Table 7 shows that most farmers did not use artificial fertilizer. It may be more commonly used among maize farmers than among coffee farmers, but the sample size is too small to assume from this data only. Most of the farmers who did not use it reported it being too expensive and/or difficult to obtain.

What percentage of your produce is sold vs consumed in the household?

Table 8. The self-reported percentage of how much farm produce is sold. The produce which is not sold stays in the household for consumption.

Farm ID	Sold produce (%)
1	60
2	40
3	60
4	N/A
5	80
6	60
7	60
8	80
9	60
10	30
11	50
12	50
13	50
14	70
15	65
16	70

As seen in table 8, the amount of produce sold vs consumed in the household can vary quite significantly. Farmers strived for as large of a surplus as possible, being able to feed the family was generally a priority but money was often needed for other expenses such as medicines, education or new crops.

How many acres of productive area is on your farm?

Table 9. The self-reported area of land being used to cultivate crops on each coffee farm/maize field, in acres.

Farm ID	Acres
1	6
2	2
3	5
4	N/A
5	7
6	2
7	6.5
8	2.5
9	10
10	4
11	2
12	10
13	4
14	2.5
15	6
16	3

Table 9 shows how the size of farms and fields varied, but most farms were likely a relatively good size compared to the average in the area. Plenty of households owned smaller plots of land with a few banana trees, some corn and a couple chickens. Cultivating a cash crop such as coffee or growing monoculture maize fields may require more land and resources than what is necessary to cultivate food for a single family.

Do you try to run your farm in a sustainable way? How?

Table 10. The self-reported ways in which farmers paid attention to sustainability.

Farm ID	
1	By aiming for financial stability
2	By sharing knowledge and teaching children to farm
3	By aiming for financial stability

4	By planning and documenting farm management strategies
5	By aiming for financial stability
6	By aiming for self-sustainability
7	By aiming for financial stability
8	By being self-reliant on some inputs
9	By keeping weeds down and mulching, preventing erosion
10	By aiming for overall "longevity"
11	By saving money, keeping weeds down, pruning and replacing dead crops
12	Feels it is difficult due to being unable to expand
13	By regular maintenance
14	By planning expansions
15	By regular maintenance, and hiring labour
16	By regular maintenance

The farmers in the study overall had sustainability in mind, at least for the sake of their own family and finances. This is seen in table 10, above. Several farmers reported that they try to work towards financial stability in the form of saving money or being self-sufficient. Some reported that they work towards sustainability in their work-routine by keeping weeds and insects down and doing regular maintenance. None of the farmers reported thinking about environmental or ecological sustainability, or freedom from pesticide dependence.

Do you share your knowledge with other farmers?

Table 11. The distribution of farmers which shared their knowledge, skills and information with other farmers.

Farm ID	
1	Yes, + farm visits
2	Yes, with friends
3	Yes
4	Yes, with contacts and students
5	Yes
6	Yes, as well as seedlings
7	Yes
8	No
9	Yes
10	Yes, with friends
11	Yes, with friends
12	Yes
13	Yes, with friends

14	Yes, + farm visits and training
15	Yes, + farm visits and seminars
16	Yes, with friends

All farmers except for one reported that they share their knowledge and skills with other farmers, as seen in table 11. This is something often seen as important within agroecology, co-creating knowledge and spreading social connectivity in farming. Farmers also saw this as a positive thing to do.

What do you think about the stability of your production and income?

Table 12. The self-reported stability of production and income on farms.

Farm ID	
1	Stability depends on season
2	Currently increasing
3	Some price fluctuations, but overall positive
4	It is stable
5	It is unstable
6	Stability depends on season
7	It is stable
8	Low stability
9	Low stability
10	Low stability due to price changes
11	Stability depends on season, but overall improved
12	Low stability
13	Low stability
14	Stability depends on season
15	Low stability
16	Low stability due to price changes

Table 12 shows the self-reported stability on the farm, and many of the farmers experience low stability or being strongly affected by seasonal changes due to drought and floods.

Do you get issues with droughts or floods?

Table 13. Farmers report on whether they had problems with droughts, floods or both.

Farm ID	
1	Droughts
2	Both
3	Droughts
4	A little drought
5	Both
6	Droughts
7	Droughts
8	A little drought
9	Droughts
10	Droughts
11	Droughts
12	Both
13	Both
14	Both
15	Droughts
16	Both

Table 13 shows that all farmers in this project reported some level of problem with droughts, floods or both. Some stated that they had problems with both, but slightly more with one or the other. But none of the farmers exclusively had problems with floods. Droughts hit these Ugandan farmers very hard overall, even when they have access to some natural water source.

5. Discussion

As seen in table 1 and table 2, average scores of insect species diversity and richness have been established from each participating farm. As seen in the tables, the average diversity and richness is overall greater in coffee agroforestry systems than in maize fields. This data can be used as a temporal baseline for comparison of insect populations in Uganda in the future.

Some external factors may have affected the data and outcome of the project, although these were avoided when possible. One example is that the dry season in Uganda would start occurring while data-collection was conducted. So, the ethanol-water traps could have attracted more insects during later stages in the project. However, the dry season started a bit late and quite slowly this year, and this did not seem to be an issue as the late traps were placed in corn fields, and these ended up with significantly lower amounts of insects overall. Also, the crop-diversity and tree species richness data used in this project did not include information on the amount, distribution, or density of said crops and trees. As a final but large factor which could have affected the results; only insects which could be trapped in bottle traps were gathered. Also, different insects would likely have different levels of attraction or interest in the water + ethanol mixture in the traps. The openings in the bottle traps would not fit too large insects, and since traps were hanging in trees, they would mostly capture flying insects or those which reside in trees. This limits the scope of insect species we could gather and provides a picture which cannot represent the entire given agroecological system.

There was a significant difference in insect diversity and richness depending on fam-type. As expected, due to previous scientific studies, the coffee system hosted more insects in more balanced populations than the maize system. One meta-analysis of 74 studies by De Beenhouwer *et al.* (2013) concluded that cacao and coffee agroforestry systems have much more biodiversity and richness than intensified plantations. The decline in total species richness when agroforestry systems got converted to monoculture plantations was measured at -46%, thus losing nearly half of all species in the agroecosystem. Still, there are degrees of intensification in agroforestry systems, and one can find differences in species richness between agroforestry sites depending on management strategies (Bhagwat *et al.* 2008). Finding more insects overall in agroforestry systems, and thereby more pollinators, is not a new occurrence. It is not a surprise that crop- or tree diversity may lead to insect diversity, but there needs to be more empirical evidence towards this fact, as well as evidence on how insect-plant interactions and agroforestry ecology works. One study by Varah *et al.* (2020) analysed pollinator richness and pollination service in agroforestry systems compared to monoculture systems in the United Kingdom. They found that the agroforestry systems hosted twice as many solitary bees and hoverflies as well as 2.4x more bumblebees than in monoculture systems. The species richness of solitary bees was 10.5x higher in agroforestry settings, and the plants in these settings also had 4.5x more seed set compared to monoculture systems. The results of this study implied that temperate agroforestry overall provides greater pollination service than monoculture, and that there is evidence to gather regarding the positive potential of well-planned agroforestry systems. The agroforestry farms visited in Uganda in this project may not have been thoroughly planned out for the sake of maintaining strong pollination, but similar patterns of higher insect richness are nonetheless seen.

One review by Isbell *et al.* (2017) looked at overall benefits of increased plant diversity in agroecosystems. They concluded that there is consistently robust evidence that strategic crop diversification can lead to increased crop yield, yield stability, pollinators, pest suppression, weed suppression and wood production. However, effects on soil nutrients and carbon are still poorly understood and requires more research in connection to crop diversification. This link to increased pollinator richness and pest suppression (due to increased insect diversity), also relates to this current study, although the focus in Uganda was not to observe specifically pollinators or predator/pest species. The overall insect diversity would still be linked to increased diversity of both pollinators and various predatory insect species. While farm type clearly differed in terms of insect diversity and richness, it did not seem to be strongly dependent on crop richness but was much more statistically correlated with higher shade tree richness. The original hypothesis was that crop richness would clearly correlate with insect richness and diversity, so the results are surprising. There was a slight correlation between crop richness and insect richness, but not as much as what was originally expected. And between crop richness and insect diversity there was only a slight trend, but not a significant one. Perhaps there being different types of trees is more important for insect populations than having crop variety. This is something that should be investigated further in agroforestry studies. There was more of a correlation between tree richness and insects, than there seemed to be between crop richness and insects. Something noteworthy here, is that the correlation tests included both coffee farms and maize fields, as the purpose was to look at these factors overall, and the first tests showed that there was a significant difference overall between the farm types. However, it could have been of interest to examine the individual farms separately as well in regard to crop- or tree richness, but I believe the sample size for maize could have been too small.

More surprisingly than farm types affecting insect populations, pesticide use overall did not affect the insects much according to the data. Insecticide use did not affect richness or diversity of insects, and herbicide use did not affect diversity. The only significant effect from pesticides came from herbicide use correlating to lower insect richness. Here it is important to keep in mind that only 5 out of the 16 farms did not use herbicides recently, so the sample size may be smaller than what is preferable for reliable results. These results from pesticide data are interesting, as one might expect that insecticides would have a larger impact than herbicides. This could be worth looking into during future research. Some research has shown that low-impact management of farms with low (or no) pesticide use will generally have a higher level of biodiversity than if there was heavy pesticide use, which is perhaps expected (Hipólito *et al*. 2018). But maybe these Ugandan coffee farms have a low enough level of stress on insect populations, so the diversity is not too impacted. Perhaps the composition of species is different after insecticide use as it "replaces" lost species. The reported types of insecticide used were mostly broad range compounds against ants and termites or other multiple other groups of species. Examples of the most common compounds used on the visited farms are Cypermethrin, Chlorpyrifos and Imidacloprid. Perhaps the insecticides are simply not having a large effect on the farms due to compounds used, lack of farmer knowledge on optimal application or other factors. Some farmers mentioned that they did not feel like the pesticides had a strong effect on the farm, but most reported feeling satisfied with the effects (perceived reduction in yield loss and perceived reduction in ant aggression during harvesting).

While it is unexpected that insecticides did not significantly affect insect populations, there are ways in which herbicides could do so. Insects at these coffee- and maize farms could have been directly affected by herbicide application, as the compounds may still be harmful despite targeting plants (Buckelew *et al.* 2000; Kraus & Stout 2019). Secondarily, the compounds causing damage on plants may upregulate defences, including those which affect herbivorous insects (Xin *et al.* 2012). Lastly, and perhaps most likely, a decrease or full loss of weeds on farms may decrease the amount of food and shelter for insects (Buckelew *et al.* 2000; Kleiman & Koptur 2023; Kraus & Stout 2019). The exact mechanisms of this are hard to predict, as a deep understanding and data of populations are necessary, but trophic cascades may occur and various elements of ecosystems on farms can be affected in diverse ways. Removing weeds and ground cover from farmland may lead to the removal of many insects, including important predatory species. This could also lead to pest species numbers increasing. Overall, a change in species compositions or richness can likely be affected if ground cover is suddenly removed, which is exactly what happens in most of the farms visited. According to most of the farmers being interviewed, they utilize herbicides and tools to remove groundcover once to a couple times per year. When visiting, it was also clear that there were no plants intended as ground cover, except in a handful of areas where coffee trees had been planted in grassy land, but these were generally not used for grazing. Strategically utilizing plant species as ground cover may help farmers control weeds taking over farmland and save money otherwise used on herbicides. Ground cover could also improve soil quality by introducing organic matter, improving texture, controlling water during both floods and droughts, protecting against soil erosion, and some plants could fix nitrogen, improving yields (Kleiman & Koptur 2023). Lack of nutrition in the soil as well as lack of funds and manure for fertilization was a concern multiple farmers had, and this could be mitigated through nitrogen-fixing plants. One potential candidate could be clover, as it would likely improve soil quality and function as feed for animals, presumably without competing too much with larger crops such as coffee and banana. Added benefits from a strategic ground-covering plant could be protection of important insects, thus a more stable farm ecosystem and added food products or animal feed.

One part of the interview consisted of the question “How do you feel about insects on your farm?”, and the follow-up question “Can they be beneficial? Why/why not?”. The overall response was that bees and pollinators were perceived as beneficial, but that all other insects were perceived as unimportant, annoying or harmful. Insects are often seen in a negative light, despite them representing 73% of all described fauna on earth (Leandro & Jay-Robert 2019). Considering that insects exist and offer important ecosystem services all over the world, protecting them is important. Over 75% of crop types rely on animal pollination, and most pollinators are insects (IPBES 2017). Pollinating insects provide numerous benefits for humanity, but their numbers have declined, and an increasing number of species are facing the threat of extinction (IPBES 2017; Wagner 2020). People will be more interested in protecting insects if they are seen in a more positive and understanding way. One study in France by Leandro and Jay-Robert (2019) analysed young adult’s perceptions of insects and investigated why some appreciate them more than others. The study asked participants of their associations with different insects, and the overall result was a negative association. They also found that invertebrates were seen as less involved in any ecosystem than vertebrates, which points to a lack of holistic understanding of insect services. Finally, they concluded that participants who were surrounded by people involved in nature conservation were more positive towards insects. Therefore, a part of the solution to improving the public image of insects may be to increase awareness and understanding of nature conservation, their importance for ecosystem functions and for humanity.

When designing and carrying out this research, potential issues were taken into consideration. Some factors may limit the quality of the project or the generalizations that can be drawn from it. Firstly, the trap design biases the insect catches, and thereby subsamples present biodiversity. The hanging trap-type utilized will attract and trap certain insects, and no single trap design can give an entirely accurate view of the entire insect ecosystem. It will be easier for flying insects or ants, which have territories in the trees where the traps are placed, to enter the traps. Different insects may also be more or less attracted to the contents of the traps, in this case Waragi liquor, water and soap. Regardless of which exact insects are attracted to Waragi, the catch can only represent a subsection of total insect diversity and richness on farms. The Kasese Waragi used during this project was made from fermented banana, which likely has a different smell than other types of Waragi or liquors.

Regarding attraction to the trap contents, this may also have changed during the project. This was to be slightly expected, since Uganda experiences strong changes in rainfall patterns twice per year, and this seasonal change was expected to happen while I visited. However, it seemed that the dry season came later and less intense than expected, which meant that there did not seem to be a big difference in attractiveness of the liquid inside the traps. If a strong dry season came in the middle of the trapping process, it would have been a potential risk for the later traps to contain more insects, but this did not happen. Also, the smell of the traps likely changed during the 2-week periods, which could have attracted or deterred different insects, but this would be the case for all traps during the project.

Another factor which will affect results is that there are degrees of intensification within any agricultural system. Agroforestry systems are expected to be less intensified than monocropping systems, but they can still be intensified. For example, through a high usage of pesticides, low crop diversity (including tree diversity and genetic diversity), the lack of a rich surrounding ecosystem, lack of cover plants or prevalent use of machinery.

Lastly, the language- and cultural barriers may have interfered with interview results, or at least with the depths of responses. A translator was employed for the interview, but there was a risk of losing some information along the way. While most of the interview questions only required relatively short and straightforward answers, the language barrier made it difficult to extract deeper or more personal information from farmers.

This was a study in a field which has not been researched much yet, if at all. Insect diversity in Ugandan coffee agroforestry systems has likely never been empirically measured and documented before. This study used simple methodology that can be adopted by virtually anyone and can be replicated on different scales. This is advantageous for researchers or farmers who want to gain a deeper understanding of insect diversity and richness in a cheap and resource-efficient way. It is also considered important to combine practical, empirical data collection with social sciences and interviews, so relevant stakeholders (in this case farmers) can voice their opinions and concerns on agroforestry and the future of agriculture. This connects to the values of agroecology, integrating social issues, politics and people into our food production. Since this study aims to establish a benchmark for insect populations, in a way which other people can build upon in the future, it is by no means complete. While incomplete on its own, it provides some much-needed insight into the valuation of agroforestry settings in the context of insect populations and agroforestry-insect interactions.

6. Conclusion

The coffee agroforestry sites displayed a higher degree of insect richness and species diversity in comparison to maize fields in the same region. This is consistent with some modern research displaying a higher arthropod diversity in more diverse and less intensified agroforestry systems. However, this may not only be because of crop diversity, as this alone did not carry a strong statistical correlation. Other factors such as there being several types of trees can also be important. A higher number of tree species, including crop trees, correlated to a higher amount of insect species diversity and richness. The results displaying a lack of diversity difference between insecticide-treated and non-treated farms, however, were more surprising. Herbicide treatment being connected to lower insect richness is interesting and may be caused by the removal of a ground-layer of plants which host insects. All farmers reported an either entirely negative or neutral view on insects and saw no benefit to their existence other than potential pollination.

Overall, insect ecology and populations in Uganda, in coffee farming and in agroforestry systems has not been researched much at all. These are important topics for the sake of ecology, economics and climate, and need more research. Raw data from insect traps used in this project may be used as a stepping-stone and reference for future diversity studies in similar agricultural sites, as repeated analyses at separate times can help us understand insect populations and agroforestry further.

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Popular science summary

Uganda is one of the largest producers of coffee in the world and is thus very important for the global market. Inversely, coffee production is very important for Uganda, being the second largest export. Most farmers cultivate on relatively small-scale farms, and coffee is a cash crop which enables many growers to provide for their households. Coffee in Uganda is typically grown in diverse settings, with many different crops cultivated above and below the coffee tree. Crops such as banana, cassava, beans, pineapple, maize and groundnuts are often grown together with coffee in so-called coffee gardens. Pesticides are not used very often, as many farmers do not have resources to acquire them. This is a generally low intensity agricultural setting, in stark contrast to how most of European agriculture works. However, while insects are more thoroughly researched in Europe, we barely know anything about insect agroecology in Africa. Insects are crucial for ecosystem services and resilience in agricultural settings all over the world, but their numbers are rapidly declining largely due to agricultural intensification.

Gaining an understanding of how insect populations are affected by agriculture is going to be an important first step to protecting them. Researching them in Uganda, where they have been scarcely researched and where agriculture is still quite connected to the environment, provides an opportunity to create an important biodiversity baseline. The purpose of the project was to create this baseline value in different coffee agroforestry settings, as well as to gain an understanding of how these farms are being managed. These management strategies were gathered using individual interviews with farmers, and insect data was collected using traps placed on each farm. This project involved 12 coffee farmers and 4 maize farmers, for the sake of comparing insect diversity and richness between farm types. Results showed that biodiversity in coffee agroforestry settings is variable, but much larger than within the monocrop maize systems. Factors such as crop- and tree richness may matter more to biodiversity than pesticide usage. The importance of this biodiversity on ecosystem services and resilience, however, requires further study.

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Appendix 1 - Consent form

An agroecological diversity assessment of insects in Ugandan coffee gardens

Processing of personal data and project participation

This is a document for consent which farmers can sign if they are interested in participating in an anonymous research project about insects and agroecology. The document should contain any information you may need to decide whether you want to participate.

My name is Ellen Nilsson, I am a biologist from Sweden. I am currently getting a master's degree in agricultural science, with a focus on agroecology. I am in Uganda to do my final thesis project and research the sustainability of coffee farms, especially from the view of insects on the farms. I am working with professors in Sweden such as Teun Dekker, who is my main supervisor for the project. This project is being done in collaboration with Professor Fred Kabi from Makerere university and Boby Ogwang, CEO of coffee company Mara Agribusiness. There is also appreciation for the research by NaCORI (National Coffee Research Institute) and ACSA (Advocacy Coalition for Sustainable Agriculture), and support from Iowa State University in Kamuli.

The project will first consist of an open interview with you, where I ask questions, and we discuss the management and values of the farm for approximately 1 hour. The questions will mostly be about topics like farm management details, crop types, income and social connections.

I will also need to set out several insect traps in the form of bottles, scattered in suitable places around the farm. They will contain ethanol, water and a little bit of soap. I will leave, and then return for a second visit around 2 weeks later, on a date and time we can agree upon. Then I will collect the insect traps, and the insects will be brought with me for counting and identification. This second visit should require less time than the first visit.

The purpose of the project is for me to conduct a legitimate research project for a master's thesis, to learn about insect ecology and about Ugandan farming methods. In addition, the purpose is also to create a baseline for insect species diversity and richness in Ugandan coffee farms. This is a subject which has not been researched much, as well as overall insect ecology and interactions in Uganda. Knowledge about insects, their behaviours and services is important to have. It can help us with issues such as pest management, yield increase, economic growth and crop quality. Coffee is one of Uganda's most important export products, providing crucial income for the entire country as well as for many farmers. Pollination of coffee and most other crops is largely dependent on insects, which will increase the quality and yield. Insect pest infestations can also be devastating for a farm, in which case it is crucial to have knowledge of their behaviours and natural predators. The insect diversity in Uganda is great, but as the human population expands and it becomes more common to use chemical pesticides, it is important to protect and understand the insects we have.

I will not openly use the name of the participant in the project, it will only be recorded for the sake of documenting consent rights, all interview answers and insect data will be completely anonymous. Geography data will be used for research purposes, but precise location will not be shown in the final paper or for anyone outside of the project.

You do not have to participate in the project or sign consent if you do not want to. You may sign consent and later withdraw it at any point if you wish, with no negative consequence to you. You would not have to justify this decision.

Some questions may be difficult to answer accurately, which is completely understandable. But I ask you to please answer as elaborately and accurately as you can, so I can get a correct understanding of the farm management.

I (the farmer) hereby agree to participate in this research project. I understand that I do not have to participate, and that my consent can be withdrawn at any time. I understand that this project will not necessarily benefit me personally. I understand that my responses will remain confidential, and that this form will not be linked to the interview or data gathered.

Signature of participant

____

Date

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